Aug. 12, 1969 Z. BONIKOWSKI ET AL 3,461,369

CONTROL SYSTEM FOR REVERSIBLE SERVO-MOTOR FOR DRIVING ELONGATED FLEXIBLE MATERIAL AT CONSTANT TENSION

Filed Jan. 24, 1967 4 Sheets-Sheet 1

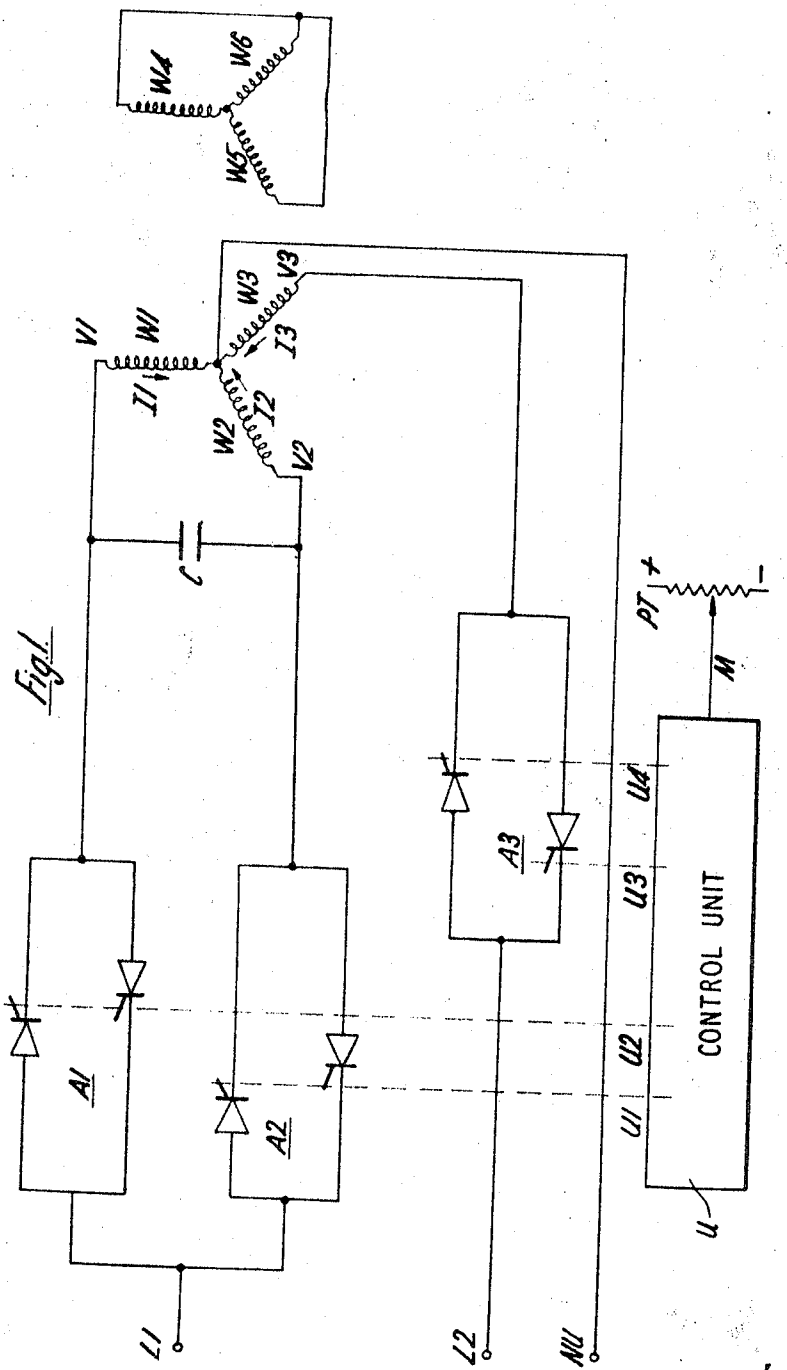


Fig.1

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Fig. 2.

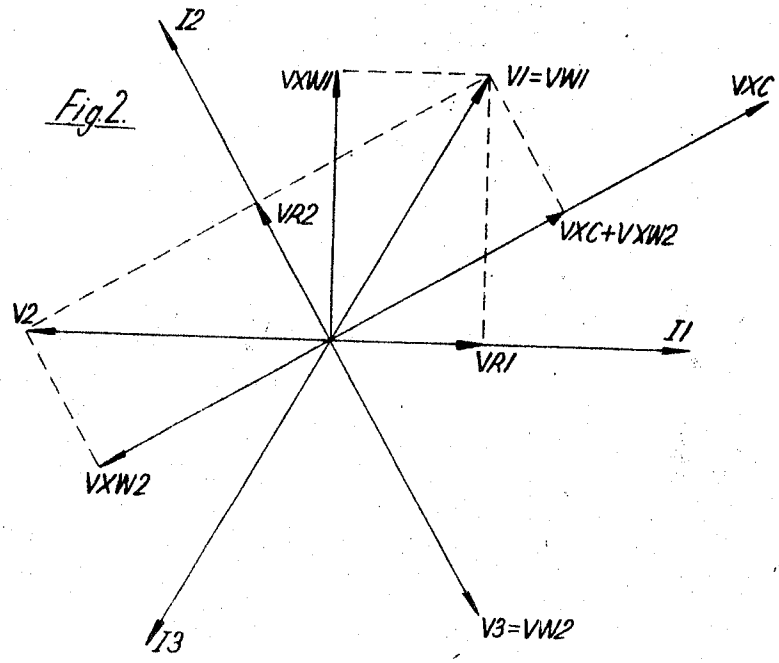
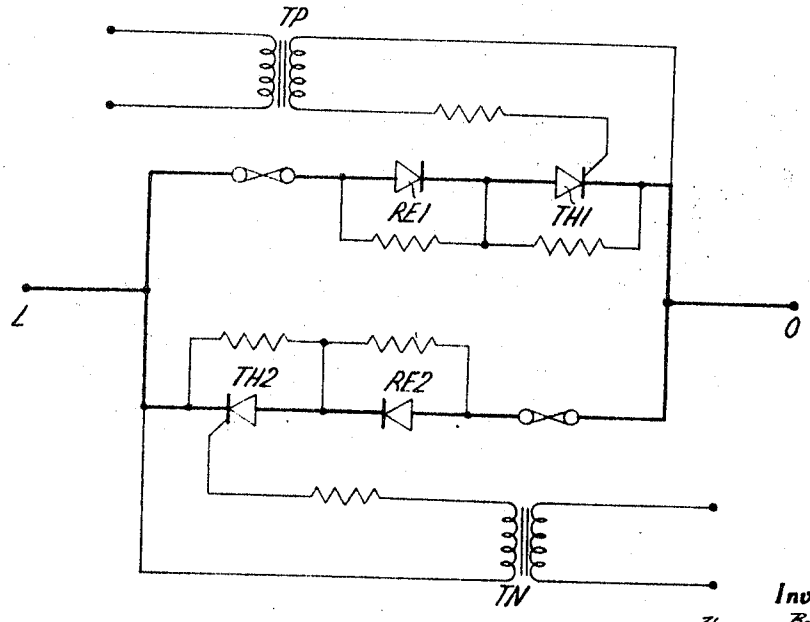


Fig. 3



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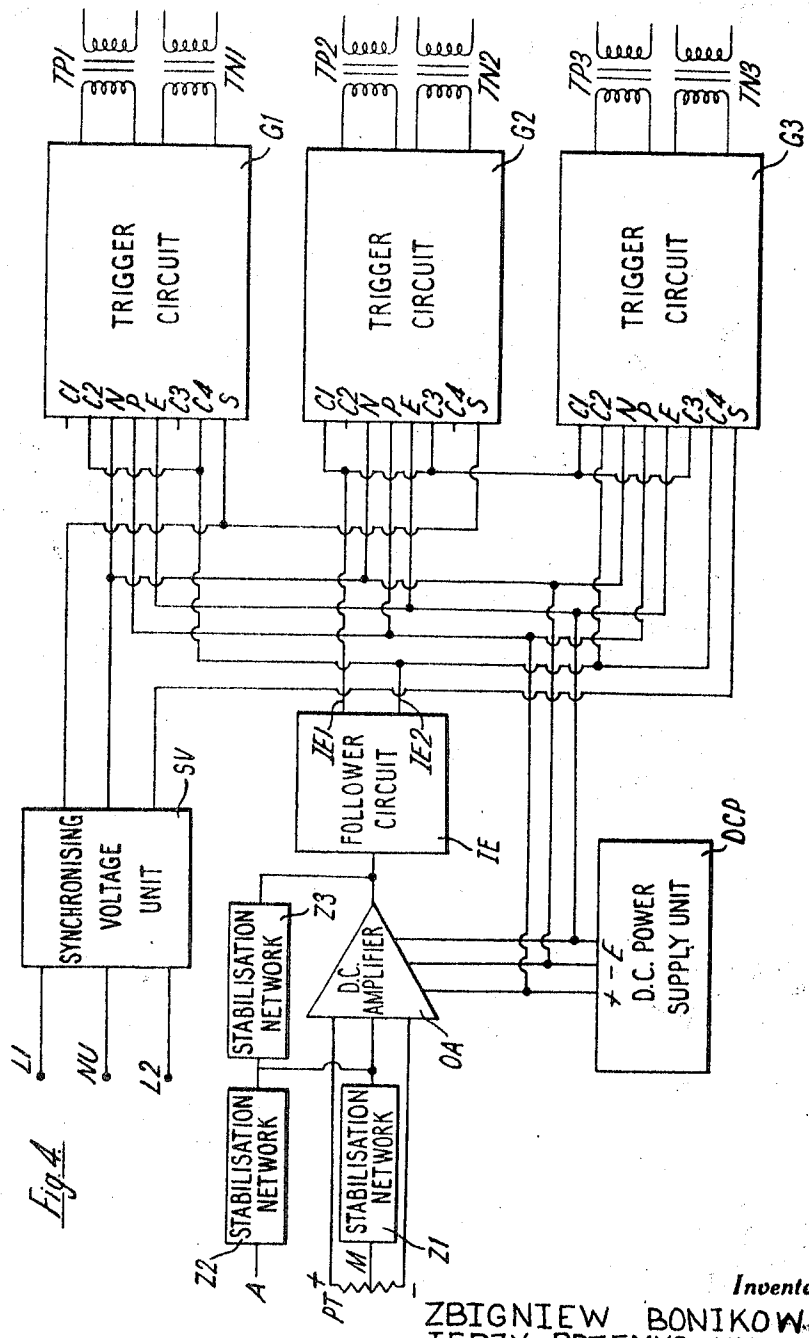


Fig 4

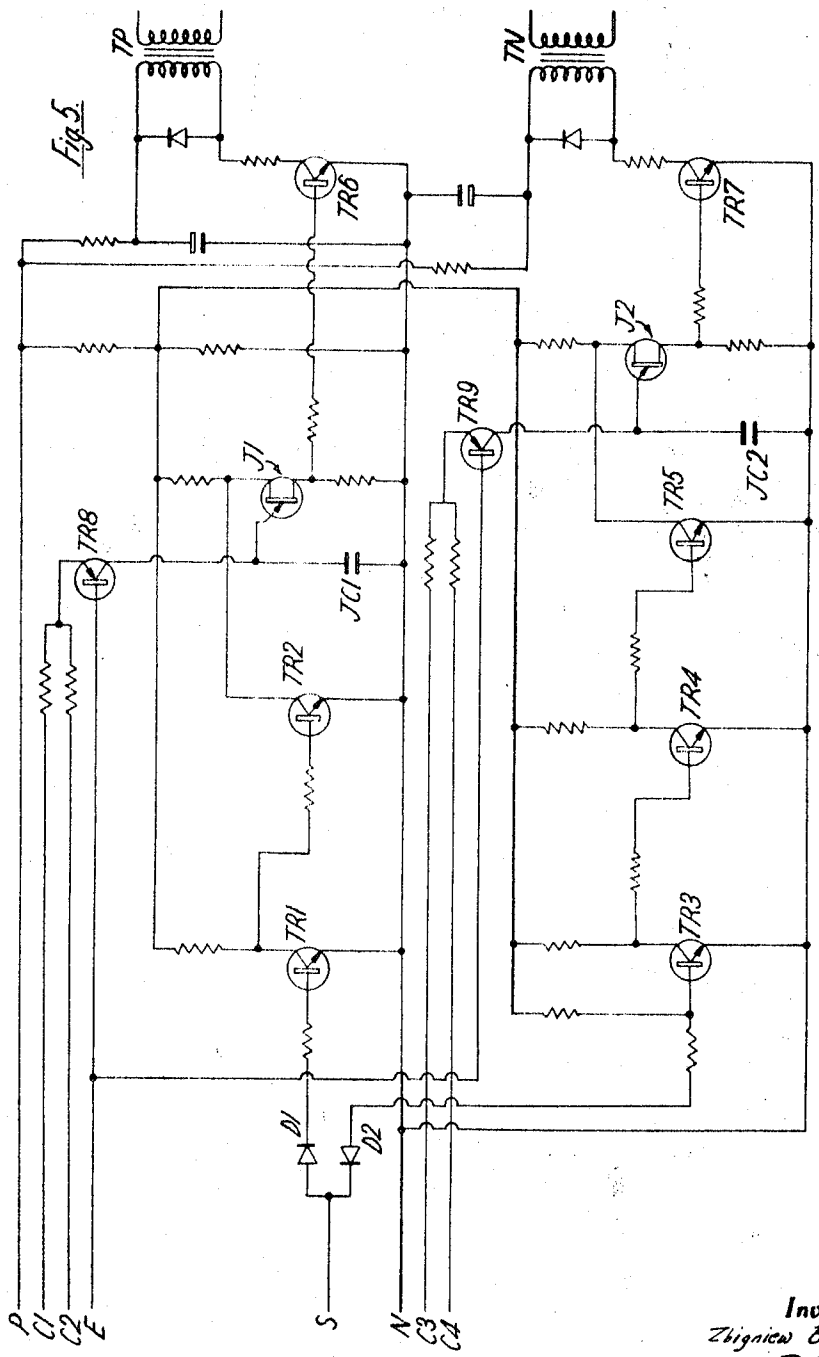
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Fig 5.



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CONTROL SYSTEM FOR REVERSIBLE SERVO-MOTOR FOR DRIVING ELONGATED FLEXIBLE MATERIAL AT CONSTANT TENSION

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U.S. Cl. 318—207 19 Claims

ABSTRACT OF THE DISCLOSURE

In a control system for a servo-motor driving elongated flexible material at a substantially constant tension the motor used is a three-phase induction motor and its three field windings are energized from a two-phase supply through three amplifiers, each controlled by a reference signal in such a way that the motor torque can be raised and, if necessary, can pass smoothly from a forward value through zero to a reverse value.

This invention relates to a servo-motor control system of the kind in which the servo-motor is required to be driven in a forward or a reverse direction in dependence on the polarity of a reference signal and with a torque that is dependent on the magnitude (positive or negative) of the reference signal.

The invention is more especially but not exclusively concerned with servo-motors used for driving elongated flexible material, for example by means of a capstan around which the material passes or by means of a take-up drum onto which the material is being wound or a supply drum from which the material is being unwound. In such cases the reference signal may be derived directly or indirectly from a sensing means which measures the tension in the flexible material and its polarity will change when the tension deviates by more than a predetermined amount from its optimum value.

It will be understood that reference to the motor being driven in a reverse direction does not necessarily mean that the direction of rotation of its rotor is actually reversed, the motor is said to be driven in a reverse direction when a reverse torque is applied by the field windings.

An object of the invention is to provide a simple control system with a high speed of response and in which the motor torque can pass smoothly from a forward value through zero to a reverse value.

In accordance with the invention, the motor used is a three-phase induction motor and its three field windings are energised from a two-phase supply through three amplifiers each controlled by a reference signal in such a way that the motor torque can be varied and reversed if necessary.

For simplicity the motor will be referred to as having only one field winding per phase, but it will be appreciated that the same effect can be obtained when there is more than one field winding per phase. Also, although reference will hereinafter be made to the "field windings" as if they were the windings of the stator only, as they normally will be, it will be appreciated that the invention is applicable to a three-phase induction motor in which a rotating field is generated in three-phase windings of the rotor which act as the "field windings" and are energized from a two-phase supply through three amplifiers.

In the system in accordance with the invention, the field winding of the first phase is connected through a first amplifier to one phase of the supply and the field winding of the second phase is connected through a second amplifier to the same phase of the supply. The field winding of the third phase is connected through a third amplifier to the other phase of the supply. There is a capacitive coupling between the first and second phase windings such that, when the first amplifier is blocked, the first and second phase windings will both be energised through the second amplifier at a relative phase sequence such that the motor is driven in one direction and that, when the second amplifier is blocked, the first and second phase windings will be energised through the first amplifier at a relative phase sequence such that the motor is driven in the opposite direction, the third phase in both cases being energised through the third amplifier. The amplifiers are controlled by the reference signal in the following way: when the signal is positive the first amplifier will be blocked, the second amplifier will supply power to the first and second phase windings and the third amplifier will supply power to the third phase winding, the output of the second and third amplifiers being proportional to the magnitude (positive) of the signal; when the signal is negative the second amplifier will be blocked and the first amplifier will supply power to the first and second phase windings and the third amplifier will supply power to the third phase winding, the output of the first and third amplifiers being proportional to the magnitude (negative) of the signal.

The first and second amplifiers can be combined to form a single amplifier with two output channels, one of which is energised when the input signal is positive and the other of which is energised when the input signal is negative. We prefer to use thyristor amplifiers.

The capacitance of the capacitive coupling between the first and second phase windings and the relationship between the resistance and reactance of each of the windings are preferably such that, when conditions are normal (i.e. in a winding system when the motor is fully excited and the tension in the material being wound is at its required value), the power supply to the three phase windings will be substantially balanced in respect of voltage and phase difference.

The maximum advantage of simplicity is obtained by using a motor with a short circuited, high resistance, rotor, e.g. a squirrel cage rotor with high resistance end plates, but it is possible to use any form of induction motor, preferably with star connected stator and rotor windings. When using a slip ring motor the rotor windings will normally be connected by resistances and the stator windings connected, through the amplifiers, to the two phase supply but, as already indicated above, these connections can be reversed.

A preferred example of a servo control system in accordance with the invention designed for the tension control of flexible material during winding will hereinafter be described by way of example with reference to the accompanying drawings in which:

FIGURE 1 is a general circuit diagram,

FIGURE 2 is a vector diagram,

FIGURE 3 is a circuit diagram of one of the amplifiers shown in FIGURE 1,

FIGURE 4 is a circuit diagram of the control unit shown in FIGURE 1, and

FIGURE 5 is a circuit diagram of a trigger circuit forming part of the control unit.

Referring to FIGURE 1, the reference signal is derived from a potentiometer PT, the position of the moving contact M of which may, for example, be an analogue of the tension in elongated flexible material

being driven by a three-phase motor, the stator windings W1, W2, W3 and rotor windings W4, W5, W6 of which are shown. The stator windings are connected through three A.C. thyristor amplifiers A1, A2, and A3 to two phases L1 and L2 and the neutral NU of a symmetrical three-phase power supply. The amplifiers each have two channels and are controlled by signals from a control unit U the input of which is the voltage on the moving contact M of the potentiometer PT. The control unit is so designed that, when the voltage on M is positive, signals from output channels U2, U3 and U4 cause amplifiers A1 and A3 to conduct in both channels and when the voltage on M is negative signals from output channels U1, U3 and U4 cause amplifiers A2 and A3 to conduct in both channels. The arrangement is such that the power output of each of the amplifiers conducting is dependent on the magnitude (positive or negative) of the reference signal.

The reactance (XC) of the capacitor C is such that, when the reference signal indicates that the condition being controlled is at an optimum value, the power supply to the three stator windings W1, W2 and W3 will be as nearly as possible balanced in respect of phase and magnitude and the motor will rotate forwards at full speed. Minor variations of the condition will cause only small variations in magnitude of the signal and a corresponding adjustment in magnitude of the motor torque but a major variation that entails a change in polarity of the reference signal will cause a reversal of the motor torque followed, if necessary, by a reversal of its direction of rotation to restore the condition to its optimum.

Assuming that amplifier A1 is conducting and amplifier A2 is blocked, that the voltage output of amplifier A1 is V1 and of amplifier A3 is V3, that the windings W1–W3 have a reactance XW1–XW3 and resistance R1–R3 respectively, then by suitable choice of stator windings, in particular the relationship between their resistance and reactance, and of capacitance for the capacitor C, the balanced condition shown in the vector diagram (FIGURE 2) can be obtained. In the vector diagram the currents I1–I3 through the windings W1–W3 are equal in magnitude and 120° out of phase and the phase angle between the voltages V1–V3 applied to the windings W1–W3 is also 120°. XW1–XW3 are equal to each other anr R1–R3 are equal to each other; if these magnitudes are XW and R respectively, then to achieve an ideal balance $XW/R=\sqrt{3}$ and $XC=2XW$.

The resistance of the rotor is such that the motor has a drooping torque/speed characteristic, this characteristic preferably following as nearly as possible a smooth curve joining the point representing minimum torque and synchronous speed to a point representing maximum or pull-out torque and standstill on the normal graph showing the relationship between speed (as a percentage of synchronous speed) and torque.

FIGURE 3 shows the circuit of one of the amplifiers A1, A2 and A3 (all of which are identical). The amplifier is a full wave A.C. amplifier. Lead L is the power supply lead (connected as shown in FIGURE 1 either to L1 or to L2) and lead O is output lead, connected to a field winding W1, W2 or W3 of the motor (as shown in FIGURE 1). Inversely connected in parallel between these leads are thyristors TH1 and TH2 and series rectifiers RE1 and RE2, the control electrodes of the thyristors being connected to the secondaries of transformers TP and TN, representing two of six transformers which will later be referred to as TP1–TP3 and TN1–TN3.

The primaries of the transformers TP and TN are connected to one of three trigger circuits G1–G3, forming part of the control unit U, which is shown in greater detail in FIGURE 4, the full circuit diagram of one of the trigger circuits being shown in FIGURE 5.

Referring to FIGURES 4 and 5, each of the trigger circuits G1–G3 has eight input terminals marked P, N, E, S, C1, C2, C3 and C4 and functions as a generator of gating pulses for both channels of one of the thyristor amplifiers A1–A3, which pulses are applied through the transformers TP1–TP3 and TN1–TN3 already referred to in the description of FIGURE 3.

Referring to FIGURE 5, the trigger circuit is based on two unijunction transistors J1 and J2, which control the charge and discharge of capacitors JC1 and JC2 respectively. One base of the unijunction transistor J1 (the upper base in FIGURE 5) is linked through a positive half cycle actuated switch formed by transistors TR1 and TR2 and a diode D1 to terminal S and the equivalent base of the unijunction transistor J2 is linked through a negative half cycle actuated switch formed by transistors TR3, TR4 and TR5 to a diode D2, also connected to the terminal S. The terminal S is connected to a sourse SV of mains frequency synchronising voltages in phase with the voltage applied to the amplifier with which the circuit is associated (FIGURE 4). The other bases of each of the unijunction transistors J1 and J2 are connected respectively through transistors TR6 and TR7 to the primaries of the transformers TP and TN.

The emitter of unijunction transistor J1 is connected through the emitter/collector circuit of a transistor TR8 to terminals C1 and C2, the base of the transistor TR8 being earthed through the terminal E. The emitter of unijunction transistor J2 is similarly connected through a transistor TR9 to terminals C3 and C4. The terminal E and the terminals P and N of the trigger unit are connected to a D.C. power supply unit DCP (FIGURE 4), the three terminals of which (reading from left to right) provide potentials of 12 v. positive, 12 v. negative and earth potential to the trigger circuits and to a D.C. operational amplifier OA and, through the operational amplifier, provide a potential of 12 v. positive to the upper terminal of potentiometer PT and 12 v. negative to its lower terminal.

It will be noted that the terminals N are connected both to the negative terminal of the unit DCP and to the neutral terminal (NU) of the synchronising voltage unit SV.

The moving terminal M of the potentiometer PT is connected through a resistance capacitance stabilisation network Z1 to the input of the amplifier OA, the output of the amplifier being fed to an invertor and emitter follower circuit IE.

When the potential on contact M is positive, a positive potential of equivalent magnitude is applied through terminal IE2 to terminals C2 and C4 of trigger circuits G1 and G3 and these units generate in the primary windings of the transformer TP1 and TP3 (during the positive half cycle) and in the primary windings of the transformer TN1 and TN3 (during the negative half cycle) pulses occurring at a time in the half-cycle before cut-off equivalent to the magnitude of the positive potential on M. This causes both thyristors in each of the amplifiers A1 and A3 to conduct during a proportion of each half cycle, equivalent to the magnitude of the positive voltage on M. When the voltage on M is negative, trigger circuits G2 and G3 are similarly energized from the terminal IE1 of the circuit IE to cause amplifiers A2 and A3 to conduct.

Thus when M is positive, the motor is driven forwards with a torque proportional to the magnitude of the positive potential on M and when M is negative the motor is driven in reverse with a torque proportional to the magnitude of the negative potential on M.

The motor control system described is particularly applicable to the tension control of flexible material and can be used for this purpose in conjunction with a sensing device in the manner described in U.S. Patent No. 3,233,-397.

When in the system described by way of example it is desired to feed back to the operational amplifier OA two variable quantities in accordance with both of which the

motor speed or torque is required to be controlled (for example wire tension and wire linear speed in a wire winding system), an additional input circuit A, through a second resistance-capacitance stabilisation network Z2, can be provided. For example the D.C. output circuit of a tachogenerator driven by the wire in a wire winding system can be fed to the circuit A, while the wire tension operates a sensing device coupled to the moving contact M of the potentiometer PT. In all circumstances there is a direct feed-back of the output of the amplifier OA through a resistance or resistance capacitance network Z3, as shown.

The servo control system in accordance with the invention has the advantage that it enables a simple, squirrel cage induction motor, without slip rings, to be driven at a speed varying smoothly through stand-still to reverse rotation in accordance with the value of a D.C. reference potential. This is of particular importance when the servo motor drives, at contant tension, flexible material being lapped onto a core in a lapping head, since to reduce the moment of inertia of such a head it is often necessary to mount such a motor or motors in a relatively inaccessible position in the head.

The motor control system in accordance with the invention is much simpler than a system employing frequency control and yet gives simultaneous control of all three phase windings of the motor. When, as is preferred and as is illustrated by the example described with reference to the drawings, the control pulses are applied to the thyristor amplifiers through independent transformers, there is little danger of the phase windings becoming interconnected owing to a short circuit through the control circuit connections.

What we claim as our invention is:

1. A servo motor control system comprising:

(a) a three phase induction motor,

(b) a first amplifier through which a first phase field winding of the motor is connected to one phase of a power supply,

(c) a second amplifier through which a second phase field winding of the motor is connected to the same phase of the supply,

(d) a third amplifier through which a third phase field winding of the motor is connected to another phase of the supply,

(e) a capacitive coupling between the first and second phase windings of a value such that when the first amplifier is blocked the first and second phase windings will both be energised through the second amplifier at a relative phase sequence such that the motor is driven in one direction and that when the second amplifier is blocked the first and second phase windings will be energised through the first amplifier at a relative phase sequence such that the motor is driven in the opposite direction, the third phase in both cases remaining energised through the third amplifier, and

(f) means for controlling the amplifiers in dependence on a reference signal which, when the signal is positive, cause the first amplifier to be blocked, the second amplifier to supply power to the first and second phase windings and the third amplifier to supply power to the third phase winding, in both cases proportional to the positive magnitude of the signal, and, when the signal is negative, cause the second amplifier to be blocked and the first amplifier to supply power to the first and second phase windings and the third amplifier to supply power to the third phase winding, in both cases proportional to the negative magnitude of the signal.

2. A servo motor control system as claimed in claim **1**, in which the motor is a three phase squirrel cage induction motor with a high resistance rotor.

3. A servo motor control system as claimed in claim **1**, in which the amplifiers are thyristor amplifiers.

4. A system as claimed in claim **1**, in which each of the amplifiers is a full wave A.C. amplifier comprising at least two thyristors connected inversely in parallel.

5. A system as claimed in claim **4**, in which in each of the two parallel circuits at least one thyristor is connected in series with a solid state rectifier.

6. A system as claimed in claim **1**, in which the capacitance of the capacitive coupling between the first and second phase windings and the relationship between the resistance and reactance of each of the windings are such that when conditions are normal the power supply to the three phase windings is substantially balanced in respect of voltage and phase difference.

7. A system as claimed in claim **6**, in which the windings are of equal reactance and resistance to each other and the reactance of each winding divided by its resistance is equal to about $\sqrt{3}$.

8. A system as claimed in claim **7**, in which the reactance of the capacitive coupling is twice that of any one of the windings.

9. A system as claimed in claim **1**, in which the power supply is constituted by two phases and neutral of a symmetrical three phase supply.

10. A system as claimed in claim **1**, in which the means by which the amplifiers are controlled comprises a control unit comprising three trigger circuits, one for each amplifier, the trigger circuits being controlled by the reference signal in such a way that when the reference signal is positive the three phase windings of the motor are energised through the second and third amplifiers and when the signal is negative the three phase windings of the motor are energised through the first and third amplifiers.

11. A system as claimed in claim **10** in which the trigger circuits are each independently coupled to one of the amplifiers through a transformer or transformers.

12. A tension control system for winding elongated flexible material at a substantially constant tension comprising:

(a) means for imparting longitudinal motion to the material driven by a three phase induction motor,

(b) a first amplifier through which a first phase field winding of the motor is connected to one phase of a power supply,

(c) a second amplifier through which a second phase field winding of the motor is connected to the same phase of the supply,

(d) a third amplifier through which a third phase field winding of the motor is connected to another phase of the supply,

(e) a capacitive coupling between the first and second phase windings of a value such that when the first amplifier is blocked the first and second phase windings will both be energised through the second amplifier at a relative phase sequence such that the motor is driven in one direction and that when the second amplifier is blocked the first and second phase windings will be energised through the first amplifier at a relative phase sequence such that the motor is driven in the opposite direction, the third phase in both cases remaining energised through the third amplifier,

(f) means for sensing the tension in flexible material and generating a reference signal proportional to the tension and changing in polarity when the tension deviates by more than a predetermined amount from its optimum value, and

(g) means for controlling the amplifiers in dependence on the said signal which, when the signal is positive, cause the first amplifier to be blocked, the second amplifier to supply power to the first and second phase windings and the third amplifier to supply power to the third phase winding, in both cases proportional to the positive magnitude of the signal, and, when the signal is negative, cause the second

amplifier to be blocked and the first amplifier to supply power to the first and second phase windings and the third amplifier to supply power to the third phase winding, in both cases proportional to the negative magnitude of the signal.

13. A system as claimed in claim **12**, in which the signal is derived from a potentiometer, the moving contact of which is moved against a biasing force under the action of changes in tension in the flexible material.

14. A system as claimed in claim **12**, in which the capacitance of the capacitive coupling between the first and second phase windings and the relationship between the resistance and reactance of each of the windings are such that when conditions are normal the power supply to the three phase windings is substantially balanced in respect of voltage and phase difference.

15. A system as claimed in claim **14**, in which the windings are of equal reactance and resistance to each other and the reactance of each winding divided by its resistance is equal to about $\sqrt{3}$.

16. A system as claimed in claim **15**, in which the reactance of the capacitive coupling is twice that of any one of the windings.

17. A system as claimed in claim **12**, in which the power supply is constituted by two phases and neutral of a symmetrical three phase supply.

18. A system as claimed in claim **12**, in which the means by which the amplifiers are controlled comprises a control unit comprising three trigger circuits, one for each amplifier, the trigger circuits being controlled by the reference signal in such a way that when the reference signal is positive the three phase windings of the motor are energised through the second and third amplifiers and when the signal is negative the three phase windings of the motor are energised through the first and third amplifiers.

19. A system as claimed in claim **18**, in which the trigger circuits are each independently coupled to one of the amplifiers through a transformer or transformers.

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